Sweet Sorghum: a good opportunity for producing bio-ethanol?

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Global oil production is rapidly approaching its peak

http://www.oildecline.com/

CO₂ atmospheric concentration in Aug. 2012 = 392.41 ppm
http://www.esrl.noaa.gov

Evolution of price at the gas station

31/08/2012
Diesel = 1.4€/l
Gasoline = 1.59€/l

It is urgent to find alternative and sustainable energies

Biofuels or agrofuels, defined as solid, liquid or gas fuels derived from biomass, are today the only direct substitute for oil on a significant scale particularly in the transport sector
poorest countries will be lead to grow biofuel crops

Less arable surfaces available for food production

Increasing staple food world market prices (good for producers, bad for urban consumers)

Instability of the staple food market

Increase of food insecurity
What are the main plants currently used?

1G Bio-ethanol

2G Bio-ethanol

Bio diesel

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**Sorghum: few generalities**

Grain sorghum = 5\textsuperscript{th} cereal

**World production (2010)**

<table>
<thead>
<tr>
<th></th>
<th>2010 Production (million T)</th>
<th>Yield (Kg ha\textsuperscript{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maize</strong></td>
<td>840</td>
<td>5195</td>
</tr>
<tr>
<td><strong>Paddy rice</strong></td>
<td>696</td>
<td>4368</td>
</tr>
<tr>
<td><strong>Wheat</strong></td>
<td>654</td>
<td>3009</td>
</tr>
<tr>
<td><strong>Barley</strong></td>
<td>124</td>
<td>2600</td>
</tr>
<tr>
<td><strong>Sorgho</strong></td>
<td>56</td>
<td>1361</td>
</tr>
</tbody>
</table>

(http://faostat.fao.org/)
## Sorghum: few generalities

### Main producers

<table>
<thead>
<tr>
<th>Country</th>
<th>2010 Production (millions of tonnes)</th>
<th>Area (1 000 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>8.8</td>
<td>1 948</td>
</tr>
<tr>
<td>Mexico</td>
<td>6.9</td>
<td>1 768</td>
</tr>
<tr>
<td>India</td>
<td>6.7</td>
<td>7 790</td>
</tr>
<tr>
<td>Sudan</td>
<td>2.6</td>
<td>5 613</td>
</tr>
<tr>
<td>Nigeria</td>
<td>4.8</td>
<td>4 737</td>
</tr>
<tr>
<td>Éthiopia</td>
<td>3</td>
<td>1 619</td>
</tr>
<tr>
<td>Argentina</td>
<td>3.6</td>
<td>751</td>
</tr>
<tr>
<td>China</td>
<td>1.7</td>
<td>547</td>
</tr>
</tbody>
</table>

(http://faostat.fao.org/)
Sorghum: few generalities

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Sorghum: few generalities

Bicolor

Verticilliflorum (wild type)

Guinea

Caudatum

Durra

Kafir

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Multi purposes crop

Biomass sorghum

Sorghum for silage

Grain sorghum

Broom corn sorghum

Sorghum for tinctures

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Combination of 2 essential traits:

1. Production of grains
2. Accumulation of sugars in the stalks
**Why sorghum for producing 1G ethanol?**

### Tropical zone
- **VS**
- **Propagation**
  - Cuttings
  - Seeds
- **Length of cycle**
  - 12-16 months
  - 4-5 months
- **Water requirements**
  - 36,000 m³ / 8000 m³ (2 cycles)
- **Adaptation to dry zones**
  - Irrigation: yes
- **Adaptation to marginal soils**
  - cane << sorghum
- **Grain production**
  - 0 << up to 6T / ha (2 cycles)
- **Ethanol production (l ha⁻¹)**
  - 6500 5600 (2 cycles)
- **Uses**
  - Sugar, Fuel
  - Food, Feed, Fuel
- **Energetic balance**
  - sorghum ⇔ maize

### Sweet sorghum

### Sorghum
- **VS**
- **Intrant needs**
  - sorghum << maize
- **Water requirement**
  - 1/3 less than maize
- **Water & Nitrogen Use Efficiency**
  - sorghum >> maize
- **Adaptation to dry environments**
  - sorghum >> maize
- **Adaptation to marginal soils**
  - sorghum >> maize
- **Grain**
  - sorghum << maize
- **Biomass**
  - sorghum ⇔ maize
  - (25 to 40T DM ha⁻¹)
- **Energetic balance**
  - sorghum >> maize

### Maize

**ADVANTAGE SORGHUM**
- Hudge potential of improvement and adaptation
- Respect of environment
- Development of rural zones
- Low competition with food crop
- Better sustainability of the production system

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Why sorghum for producing ethanol?

The Adaptability of Sorghum

Sugar cane

Sweet Sorghum

Grain & Energy Sorghums

Limit of cereals

Sugar beet
2nd generation EtOH or methane production: a biomass sorghum with the following traits:

- **High biomass** production (30-40 TDM ha\(^{-1}\)) which means a plant height > 3.5-4m and a long cycle (4-5 months)
- Good **tolerance to low temperature**
- A **photosensitivity** adapted to induce late flowering
- A **good quality** of the raw material which must be poor in lignin (bmr trait) to increase **digestibility** of the tissues
- A good **tolerance to lodging** (antagonistic with bmr trait)
- **Tolerance to water deficit** / high water use efficiency

For that purpose, grain production is not essential
2nd generation EtOH or methane production: a biomass sorghum

Possible combination of:
- high stalk biomass
- low lignin content
- good digestibility of fibres

Mean dry weight of main stem (g)
2\textsuperscript{nd} generation EtOH or methane production: a biomass sorghum

Photosensitivity

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2 1st generation EtOH and/or cogeneration: a sweet sorghum with the following traits:

- High biomass production (30-40 TDM ha⁻¹) which means a plant height > 3.5-4m

- high accumulation of soluble sugars in stalks, °Brix% of 15 to 20 with 80% of saccharose

- juicy stalks

- high energetic value of the bagasse for cogeneration which means more fiber with lignin

- adaptation to marginal soils (acidity, Al toxicity, P deficiency)

- adaptation of crop cycles (complementary with sugar cane)

  for that purpose, grain production is not wishable
1\textsuperscript{st} generation EtOH or cogeneration: a sweet sorghum (Brazil)

Possible combination of

- °Brix% with juice
- °Brix% with stalk biomass
- Al tolerance
- complementarity sugar cane cycles (1.8 million ha)

106 accessions

Sweet sorghum

Sugarcane

gene for tolerance to aluminum toxicity: \textit{Alt}_{SB}

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1\textsuperscript{st} generation EtOH combining grain and fodder: a sweet sorghum with the following traits:

- **High biomass** production (20-30 TDM ha\(^{-1}\)) which means a plant height ± 3m and a long cycle (4-5 months)

- a mean production of **grain** (1.5 to 3 T ha\(^{-1}\))

- high accumulation of **soluble sugars in stalks**, °Brix% of 15 to 20 with 80% of saccharose

- **juicy** stalks

- high value of the **bagasse as fodder** which means high digestibility (=\(bmr\) trait = low lignin content in bagasse)

- adaptation to **marginal soils** and **rainfall distribution** (stay green, adapted photosensitivity)

**for that purpose, grain production is essential**
Processes of accumulation are not well characterized

What is the right kinetic of sugar accumulation in stalks?

Is there a competition between sugar accumulation and grain production?
Accumulation of sugar in stalks

(Source: Gutjahr 2012)

Glucides are accumulated before flowering

Flowering

Glucides content (g/stem)

(Source: Gutjahr 2012)

Ablation of panicule has low influence on sugar accumulation.

Competition between sugar accumulation and grain production seems low.
There is a competition grain/sugar, but it is low
There is a great diversity in sorghum which must be used without forgetting landraces

95 T FW + 5 T grain + 7-12% sugar
60 T DW + 4 T grain + °Brix 18
20 T DW + 5 T panicule + °Brix% 16 + 12 T juice
65 T DW + 2.2 T grain + 18.7 °Brix%
44.8 T FW cane + 4 T grain + 18.4 T juice + 12 °Brix%

Almodares et Hatamipour 2011
Zhang 2010
Pers. Com. 2011
Schaffert 2010
S. Rao 2009
Case study in Andalusia (Spain).

<table>
<thead>
<tr>
<th>Economic analysis</th>
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<tbody>
<tr>
<td><strong>Investment cost</strong></td>
<td>30 million €</td>
</tr>
<tr>
<td><strong>Operative costs</strong></td>
<td></td>
</tr>
<tr>
<td>Biomass 29-34 €/t (34 €/t dry basis with a 38% of sugar in the stalk dry)</td>
<td>6.23-7.30 million €/year</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>2.69 million €/year</td>
</tr>
<tr>
<td>Other</td>
<td>1.22 million €/year</td>
</tr>
<tr>
<td><strong>Incomes</strong></td>
<td></td>
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<tr>
<td>Final products</td>
<td></td>
</tr>
<tr>
<td>Bioethanol price 450-800 €/m³</td>
<td>5.63-10.00 million €/year</td>
</tr>
<tr>
<td>Supported electricity price from biomass 16.81 - 11.38 €/kWh (10 MWe installed has a production of 86,400 MWh per year, 360 days and 24 h per day)</td>
<td>14.52 – 9.83 million €/year</td>
</tr>
</tbody>
</table>

Table 32: main costs and incomes included in the economic analysis of the case study

Considering the information showed on Table 33, the range of total cost is 10.14-11.21 million €/year and the range of incomes is 15.46 – 24.52 million €/year.

If the total investment cost is fixed on 30 million €, the payback can vary between 2.5 years (the best case) and 7.5 years (the worst case).

These data are quite fantastic!

but let’s keep our head cool… and don’t create so high expectations that this plant would not be able to meet !!!

.... Remember *Jatropha curcas* !!!

Sweet sorghum has a great potential for producing bio-ethanol but this is not a miraculous plant!
Sweet sorghum: a multiple purpose crop